

THE COMPOSITE ANALYTIC AND SIMULATION PACKAGE OR RFI (CASPR) ON A CODED CHANNEL

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ABSTRACT — CASPR is an analysis package which determines the performance of a coded signal in the presence of Radio Frequency Interference (RFI) and Additive White Gaussian Noise (AWGN). It can analyze a system with convolutional coding, Reed-Solomon (RS) coding, or a concatenation of the two. The signals can either be interleaved or non-interleaved. The model measures the system performance in terms of either the E_b/N_0 required to achieve a given Bit Error Rate (BER) or the BER needed for a constant E_b/N_0 .

I. INTRODUCTION

Stanford Telecom developed CASPR for NASA Goddard Space Flight Center's (GSFC) Communications Link Analysis and Simulation System (CLASS). CASPR determines the effect of RFI on a satellite communications signal transmitted across a non-linear Tracking and Data Relay Satellite II (TDRS-II) channel. This system required the development of several new and unique analytic algorithms for determining the signal performance in the presence of RFI.

CASPR determines the performance of a signal in the presence of RFI and AWGN. The performance is measured in terms of either the E_b/N_0 required to achieve a given BER or the BER needed for a constant E_b/N_0 .

Two types of RFI are analyzed: pulsed Gaussian noise and pulsed sinusoidal noise. CASPR can model multiple pulsed Gaussian and sinusoidal sources transmitting simultaneously with Poisson or periodic arrival distributions and unique EIRPs, duty cycles, and pulse durations.

CASPR supports a wide variety of coding schemes and system parameters. These are shown in Table 1.1.

Table 1.1: Input Parameters

Parameter	Possible Values and Units
E_b/N_0	any real number in dB
Data Rate	
Type of Coding	1) Convolutional rate, 1/2 or 1/3 2) RS (255,223) 3) Concatenated Convo/RS (Either may be with or without ideal interleaving)
Signal Format	NRZ, BiPhase
PN Coding	Yes, No
Signal Modulation	BPSK, QPSK
Clip Level (AM/AM)	dB's above mean signal power
AM/PM	dB/deg above mean signal power
RFI	See Section II

SECTION II. RFI ENVIRONMENT

CASPR is designed to predict the performance of TDRS user satellite communications in the presence of RFI and AWGN. As shown in Figure 2.1, RFI can corrupt communications signals for both forward and return links, primarily corrupting the space-to-space links.

CASPR treats RFI pulses with common characteristics (pulse duration, type, EIRP, and duty cycle) as a single source. The pulse duration is the length of time the pulse exists; the type is either Gaussian or sinusoidally varying (SV); the EIRP is the RFI power; and the duty cycle is the proportion of time the pulse is present. Noise-like RFI is modeled as pulsed bandlimited additive white Gaussian noise (AWGN). SV RFI is modeled as pulsed sinewave interference with a constant amplitude and a random initial phase and frequency. The frequency of the sinusoidal

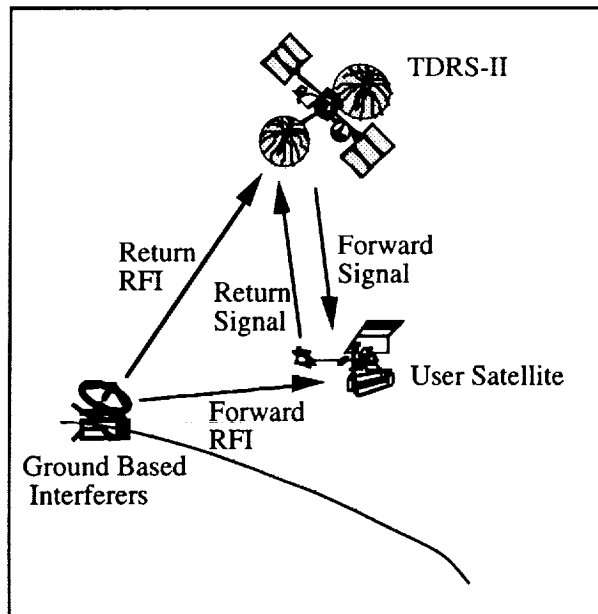


Figure 2.1: RFI Noise in Satellite Communications

pulse is constant over the pulse duration. However, different pulses have different frequencies, which are uniformly distributed within the TDRS transponder bandwidth.

SECTION III. OVERVIEW

This section gives an overview of the model. The system includes two subsystems: the channel subsystem and the coding subsystem. This section also describes the input/output at each stage of the model.

Figure 3.1 shows the CASPR flow diagram. The user first enters input parameters to the channel subsystem, which models the signal and the RFI environment and subsequently predicts symbol statistics at the input to the channel decoder. These symbol statistics are then entered into the coding subsystem, which determines the BER.

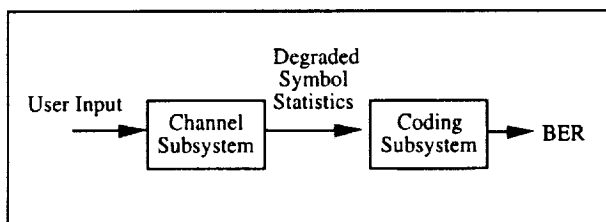


Figure 3.1: The CASPR Model Flow Diagram

The channel subsystem uses the system parameters as input and predicts symbol statistics at

the TDRS-II receiver (before coding). New algorithms were developed which use a characteristic function approach to quickly determine the symbol statistics at the TDRS-II receiver. In addition, the channel system contains a Monte-Carlo simulator that determines more precise statistics. A single analysis can use either the Monte-Carlo simulator or the characteristic function approach to determine the symbol statistics.

The coding subsystem uses the symbol statistics generated by the channel subsystem to determine the signal BER. The symbol statistics characterize the symbols at the input to the decoder. The symbol statistics for each source include the average burst length and the 8-level soft decision bin probabilities of the symbols. These bin probabilities correspond to the probability of a received symbol being quantized to a particular soft decision level of the Viterbi decoder.

The RFI, which occurs in pulses, causes burst errors in the signal. Each RFI source causes a different type of burst statistic. The analysis separately characterizes the signal degradation due to each of the RFI sources and for AWGN alone. The analysis also calculates the probability of transitioning from one type of source to another, based upon the duty cycles and characterizes the signal degradation for the system as a whole. This conditional information is used in the coding subsystem modules discussed below.

The system uses one of several different program modules, depending on the coding scheme and whether or not the symbols are interleaved [1,2,3]. CASPR uses a new importance sampling algorithm to determine the BER for a non-interleaved, convolutionally encoded signal [1]. It uses a new Markov chain analysis to determine the BER for a non-interleaved RS coded channel [2], and it uses a new combined simulation and Markov chain analysis to determine the BER for a concatenated convolutional / RS encoded signal [3].

IV. CHANNEL SUBSYSTEM

Two different modules exist in this model which can calculate the degradation due to AWGN and RFI noise. The first is an analytic model which uses a characteristic function approach, and the second is a simulation.

The analytic model has a run-time which is independent of the BER, whereas the simulation's run-time is inversely proportional to the BER. The analytic model is recommended when a low BER is required (i.e. less than 10^{-4} before any coding gain is taken into account). The simulation model is slower in many cases, but makes fewer assumptions.

A. The Characteristic Function Module

The analytic model uses a characteristic function approach. The characteristic function approach is based on the general approach described in [4] but uses new characteristic function equations. The analysis separately calculates the characteristic function of a desired symbol and of each RFI source which interferes with the desired symbol. It then combines these characteristic functions by multiplying them together. Finally, it calculates the 8-level soft decision bin probabilities from the characteristic function.

The model has two modes of operation, depending on the pulse width of the RFI. If the RFI pulse width is larger than the symbol, the errors will occur in bursts. In this case, the model separately calculates symbols corrupted with each RFI source. If, on the other hand, the RFI pulse width is smaller than the symbol duration, the module calculates a composite characteristic function.

B. The Simulation Module

The simulation module calculates the degradation due to AWGN, RFI, and amplifier nonlinearities through the use of a straightforward simulation. Additionally, it demodulates and detects the distorted symbols. It then 8-level quantizes the symbols and tabulates the statistics discussed in Section I.

V. CODING SUBSYSTEM

The coding section of the analysis follows the symbol statistics section. Its inputs are the outputs from the symbol statistics section. In summary, these are the number of RFI sources, their lengths, the probability of transitioning from one type of source to another, and a set of 8-level soft decision levels for each source.

This subsystem can analyze systems which use either convolutional coding (with Viterbi decoding), RS coding, or a concatenation of the two. It can analyze any of the above systems both with and without ideal interleaving. This interleaving is on the bit level for the convolutional code and on the symbol level for the RS code. For the concatenated coding system, this interleaving may be on either or on both codes. A list of all possible analyses follows:

1. No coding
2. Convolutional coding only
 - 2a. With convolutional interleaving
 - 2b. Without convolutional interleaving
3. RS coding only
 - 3a. With RS interleaving
 - 3b. Without RS interleaving
4. Concatenated Convolutional / RS coding
 - 4a. With both convolutional and RS interleaving
 - 4b. With convolutional interleaving only
 - 4c. With RS interleaving only
 - 4d. Without any interleaving

Due to the large number of possible analyses, it was necessary to develop several different algorithms, including both simulation and analytic models. The total number of algorithms incorporated here is six, three of which have been specially developed for this model. The following is a list of these six, the last three of which are the new models.

1. Uncoded (UnCod)
2. R_0 analytic approximation(R_0) [4]
3. Conventional convolutional coding simulation (VitS)
4. Importance sampling convolutional coding (ImpS) [1]
5. RS stand-alone analytic, using a Markov Chain (MC) [2]
 - 5a. With interleaving (RS-MC (A))
 - 5b. Without interleaving (RS-MC (B))
6. RS concatenated analytic, using a Markov Chain [3]
 - 6a. With interleaving (Con-MC (A))
 - 6b. Without interleaving (Con-MC (B))

Figures 5.1 - 5.4 show the relationship between the type of analysis run and the model which is used. Also given are the type of bursts which occur at each step. The letter F stands for fixed, G stands for geometrically distributed, B stands for bursts, and W stands for the wait time in-between bursts. For example, FB means that the bursts have a fixed length.

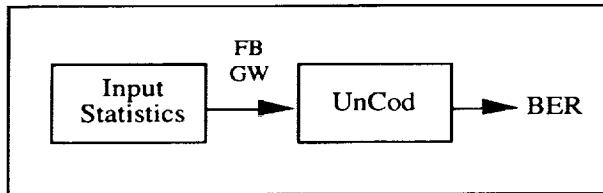


Figure 5.1: No Coding

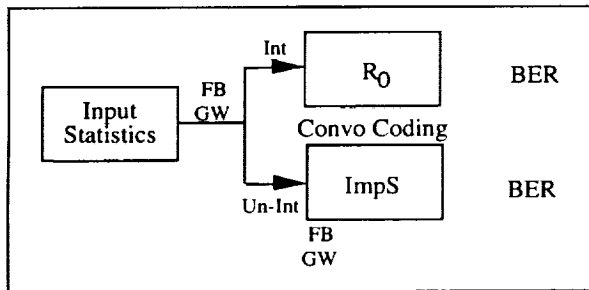


Figure 5.2: Convolutional Coding Only

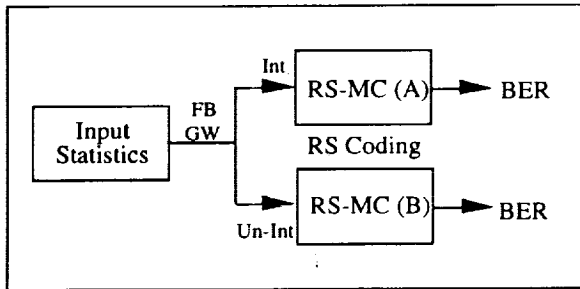


Figure 5.3: RS Coding Only

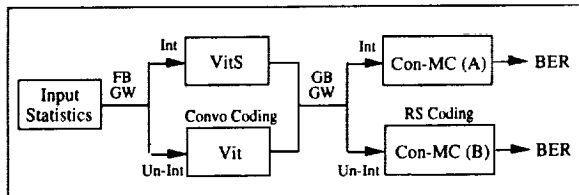


Figure 5.4: Concatenated Convolutional/RS Coding

These models contain two different types of burst statistics. Note that the input to the first level of coding in each case has bursts which are of a fixed length, but which have a geometrically

distributed wait time in-between them. This is taken directly from the input statistics of the model. However, in the concatenated model, the input statistics to the RS coder have burst lengths which are geometrically distributed. The reason for this is discussed below, in Section C.

We outline the algorithms which the coding subsystem uses in each of the six models in the following paragraphs. Run-times given are for an HP 9000 series 800 computer.

A. The Uncoded Module (UnCod)

This module simply adds up the noisiest four of the eight soft decision levels to come up with the BER.

B. The R_0 Analytic Approximation Module (R_0)

This module first determines the cutoff rate, R_0 , from the 8-level soft decision values for the channel as a whole, using a simple equation. It then determines the BER through a curve fit which is based upon a simulation. The total run time for this module is less than one second.

C. The Conventional Convolutional Coding Simulation Module (VitS)

The VitS module is a straightforward simulation. The noisy channel outputs are simulated using a random number generator. The decoding process is also simulated in a way which directly corresponds to the decoding process of an actual Viterbi decoder. The output statistics here are the BER, the mean burst length, and the mean time between bursts.

Both the burst length and the time between bursts are assumed to be geometrically distributed, where a geometric distribution is defined as follows:

$$P(b = m) = P_B(1 - P_B)^{m-1}, \quad m > 0$$

where $P_B = 1 / \text{mean burst length}$

Note that the probability of burst length or wait time falls exponentially as the length or the time increases. The model assumes that half the bits in a burst are in error, including the first and last bit. By definition, none of the bits in a wait time are in error.

Since this module is a simulation, its run-time is inversely proportional to the output BER. The Viterbi decoding process is relatively complicated, so the run-time for a low BER could be prohibitively long. However, for concatenated convolutional / RS codes, the necessary output BER of the Viterbi decoder is relatively high, even if the total system BER is very small. Typically, an inner code BER of 10^{-3} is sufficiently small. This BER can be simulated with reasonable accuracy in about 5 minutes.

D. The Importance Sampling Convolutional Coding Module (VitS)

The ImpS module has the same inputs as the VitS module, and it uses the same geometric distribution assumption. The only output, however, is the BER.

Since this module may have to deal with very small BER's, it must be more efficient than the VitS module. It achieves this increase through importance sampling, a technique used to bias the channel statistics so that error (important) events occur more frequently than they would in an unbiased simulation [5]. It uses a weighting function to offset this bias. This function gives the ratio of the probability of a specific error occurring in an unbiased channel to the same error occurring in the biased channel. These values are computed through the use of a Markov chain technique.

The run-time of this model is independent of the output BER. To get a reasonable level of accuracy takes about 1 hour with this model. Note that for a BER of less than about 10^{-4} , the run-time would be less if the VitS model were used instead of the ImpS model. Therefore, the model always initially attempts to obtain the BER through the VitS module. However, if it appears that the BER will be less than 10^{-4} after a short period of time (100,000 bits), the model switches over to the ImpS module.

E. The RS Stand-Alone Analytic Module (RS-MC)

The RS-MC analytic module makes several simplifications in order to make the analysis achievable. First, each bit may be in only one of two states: the burst state or the no-burst state.

The statistics of the no-burst state are found by taking the weighted average of the statistics of all the input states except the no-burst state. Second, each burst is assumed to completely overlap a symbol or symbols, so that either all of the bits in a symbol or none of the bits in a symbol are in the burst state.

The analysis proceeds as follows: the module uses the input statistics to calculate a probability of symbol error for each of the two states. A MC calculates the probability that a symbol is or is not hit by a burst. If a symbol is hit, the MC calculates the probability that the symbol is at the beginning, the end, or anywhere in the middle of the burst. If RS interleaving is used, RS-MC (A) calculates the BER based upon symbol errors which are independent of one another. If RS interleaving is not used, RS-MC (B) calculates the BER based upon dependent symbol errors (several symbols in a row in error).

This is an analytic module, so the run-time is very short, about 5 seconds, and is independent of the BER.

F. The RS Concatenated Analytic Module (Con-MC)

The Con-MC analytic module assumes that the bursts which are output from the Viterbi decoder and into the RS encoder come in bursts which have geometrically distributed burst and wait times. The mean value of these two distributions (the only value necessary to characterize them) is determined in the VitS module described above.

This model uses two Markov chains. The first calculates transition probabilities for transitions from one bit to another. The second calculates transition probabilities for transitions from one symbol to another. Module Con-MC (A) calculates the BER for the ideal interleaving case. It uses information from the first MC only and assumes that bursts errors occur for bits within a symbol. However, it assumes that these bursts errors do not occur from one symbol to another, so symbol errors are independent. Module Con-MC (B) calculates the BER for the non-interleaved case and uses information from both Markov chains. It assumes a geometric distribu-

tion of burst errors throughout, so symbol errors occur in bursts.

Like the previous module, this one is analytic, so the run-time is very short, about 5 seconds, and is independent of the BER.

VI. RESULTS

This section presents results for codes generated by three different coding systems: a convolutional code, a RS code, and a concatenated convolutional / RS code. These correspond to Models 4, 5, and 6, respectively. Each figure graphs the BER against E_b/N_0 . The convolutional codes used are rate 1/2, constraint length 7. The RS codes used are (255,223) codes, which have 8 bits per symbol.

Figure 6.1 shows results for convolutional coding, both with and without interleaving, and for an RFI environment with six sources. Each

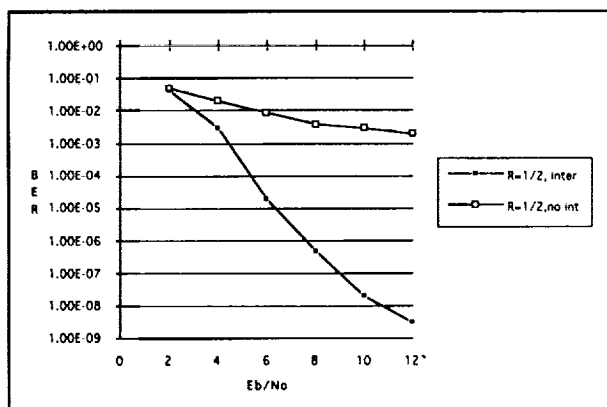


Figure 6.1: Convolutional Coding With and Without Interleaving

RFI burst has a length of 22 coded symbols. Note that interleaving results in a large improvement.

Figure 6.2 is for a RS code, again with and without interleaving with one RFI source. It has infinite power and a duty cycle of .005. We present results for bursts of lengths 5 and 20. Note that interleaving results in little improvement for a burst length of 5, but a lot of improvement for a burst length of 20.

Figure 6.3 shows results for a concatenated code without interleaving. There is no RFI here. For high BER's, the model results were compared to simulation results, and the two models agreed to within .1 dB.

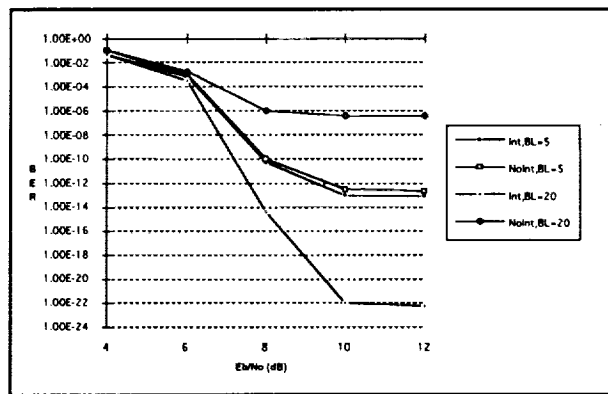


Figure 6.2: RS Code With and Without Interleaving

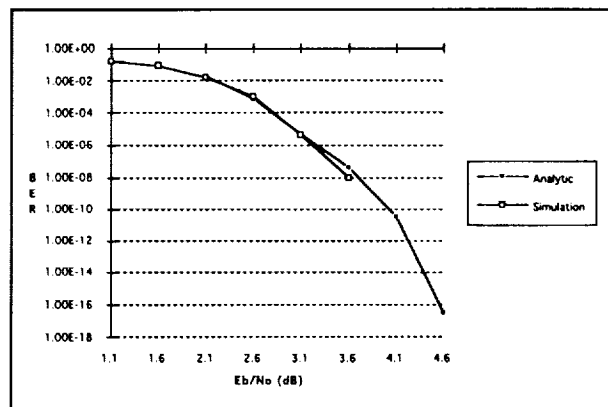


Figure 6.3: Results for a Concatenated Code Without Interleaving

VII. CONCLUSION

This paper describes a model which can analyze the degradation due to RFI for a coded communication system. It can model many coding schemes including: convolutional, RS, and a concatenated RS convolutional. It can also model any combination of interleaving or non-interleaving. The model is made up of several different modules, including four which use algorithms developed specifically for CASPR.

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